Computer-based Clinical Instrumentation for Processing and Analysis of Mechanically Evoked Electromyographic Signals in the Upper Limb

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Abstract: **A computer-based clinical instrument was developed to simultaneously acquire, process, display, quantify and correlate electromyographic (EMG) activity, resistive torque, range of motion (ROM), and pain responses evoked by mechanical stimuli (i.e. passive elbow extensions) in humans. This integrated multicahnnel system was designed around AMLAB® analog modules and software objects called ICAMs. Each channel consisted of a time- and frequency-domain block, a torque and angle measurement block, an experiment number counter block and a data storage and retrieval block. The captured data in each channel was used to display and quantify: raw EMG, rectified EMG, smoothed rectified EMG, root-mean-squared EMG, fast Fourier transformed (FFT) EMG, and normalized power spectrum density (NPSD) of EMG. Torque and angle signals representing elbow extension measured by a KIN-COM® dynamometer during neural tension testing, as well as signals from an electronic pain threshold marker were interfaced to an AMLAB workstation and presented in one integrated display. Calibration was achieved by using low-level square and sine waves. Weight compensation was implemented by developing a special interface between the AMLAB and the KIN-COM dynamometer. Although this system was designed to specifically study the patterns and nature of evoked motor responses in Carpal Tunnel Syndrome (CTS) patients, it could equally well be modified to allow acquisition, processing and analysis of EMG signals in other studies and applications.**

In this paper, we describe an integrated system to simultaneously study and analyze the mechanically evoked electromyographic, torque and ROM signals and correlate various levels of pain to these signals.

Keywords: Mechanically evoked EMG; Clinical instrumentation; Biomedical signal processing; AMLAB; KIN-COM, Carpal Tunnel Syndrome, Movement analysis.

I. INTRODUCTION

Advances in understanding the neuromuscular interaction have been increasingly dependent on the ability to simultaneously record sensory and motor responses during a particular motor task. In clinical practice, the outcomes of passive diagnostic techniques in different positions of the upper limb is interpreted with respect to pain provoked by the movement, the through-range muscular stiffness and the maximum range of motion.

Presently, it is difficult to interpret the upper limb test outcomes because they yield little quantitative information concerning the EMG activity of the muscles, range of motion, through-range resistive torque and a proper system for report of pain onset and pain limit. Therefore, the analysis of neuromuscular interaction during passive movements requires an integrated instrument for collective measurement and control of variables such as angular velocity, range of movements, resistive torque, EMG activity of involved muscles and a mechanism for reporting of pain occurrence. In such a measurement system each variable is a type of signal.

Traditionally, life scientists, biomedical engineers and clinical researchers have used a number of "single function instruments" to record, store and analyze biomedical signals in basic or applied research. Often in these single unit instruments, flexibility and configurability were sacrificed for the ease of use. As a result, these instruments have been limited in enabling researchers to simultaneously associate and correlate different signals in one working environment. New developments in computer-based instrumentation using instrument-oriented programming offers the flexibility to address these limitations and enable us to design and implement multiple unit instruments in one system. Such integrated systems enable clinicians and researchers to associate and correlate multiple signals in one environment and empowers them to address their specific clinical research and application needs in an efficient and user-friendly fashion.

Therefore, to facilitate advancements in the study of patterns and the nature of evoked motor responses in general and in CTS patients in particular, we have developed an integrated multi-function data acquisition, processing and analysis system to study upper limb movements in a comprehensive way.

II. INSTRUMENTATION

A. System Hardware

KIN-COM dynamometer: A KIN-COM dynamometer (Chateaux Inc., Tennessee USA) was used for measuring peak torque production and range of motion during passive elbow extension. The resulting ranges of motion and torque data by KIN-COM were interfaced to an AMLAB (AMLAB International, Sydney Australia) workstation by using appropriate ICAMs. Since ROM and resistive torque are not inherently electrical signals, they are first converted to proportional voltage fluctuations by suitable transducers in KIN-COM.

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Microswitch: A battery-operated microswitch provided a mechanism for generating digital rectangular pulses to indicate occurrence of pain onset and maximum tolerable pain during elbow extension in the Upper Limb Tension Test (ULTT) position. The duration of these pulses was set at 110 msec. This switch was connected to a data-acquisition card in the front-end of the AMLAB workstation.

AMLAB Workstation: The integrated EMG system was designed and implemented around AMLAB analog modules and software objects called ICAMs (Instrument Component Associate Measurements). In AMLAB, ICAMs work as elemental-hardware-instrument units. An ICAM is a graphical object that defines a specific processing function performed by the AMLAB processor [1, 2]. An instrument is made up from a front-end analog module, a large selection of ICAMs and associated data paths, which define the processing, measurement or control system required and can be saved, reused or modified when needed. Therefore, the AMLAB system is a set of electronics modules and a collection of mathematical and signal processing concepts combined in a computing context. This combination can be programmed by a simple-to-use graphics compiler, which enables programmer as well as non-programmer professionals to write complex software for diagnostic or research purposes.

B. *System software*

To plan an instrument in AMLAB, it is important to have and to follow a clearly defined procedure. The input signals required for development of the mechanically evoked integrated EMG system comprised of EMG signals from involved muscles, torque and angle signals from the KIN-COM dynamometer, and a rectangular pulse from a hand-held pain indicator switch.

For adequate presentation of surface EMG and ROM/torque signals, we chose a sampling rate of 1000 Hz for EMG signals and a sampling rate of 100 Hz for movement signals picked up by KIN-COM. Four functional blocks were required for implementation of the integrated EMG system. These functional blocks were comprised of a block to display the time- and frequency-domain EMG, a block to capture analog signals (torque and angle) from KIN-COM dynamometer and a digital electronic signal from a hand-held switch, a block to count various stages of the experiment and to run all traces simultaneously and a block to store the data stream to disk for future retrieval.

C. *System calibration and reliability*

To check the validity and accuracy of measurements made by the overall system it was necessary to perform initial calibration check of individual modules constituting the system. As the overall system comprised of AMLAB analog electronic modules and signal processing instruments as well as the variables captured by the KIN-COM dynamometer, the overall system required calibration of analog electronic modules, calibration of ICAMs inside AMLAB, calibration of ROM, torque and limb weight signals generated by the dynamometer. To verify the overall accuracy and reliability (see [3]) of the measurements made by the multi-channel EMG system, we adopted a calibration signal and a procedure used in testing the performance of electrocardiograph (ECG) machines. A biopotential signal generator (Dynatek Nevada, ECG 200, USA), simulating an EMG source, was attached to the input of each EMG channel comprised of a bioamplifier module and the associated signal processing ICAMs inside AMLAB. To test the linearity, frequency response and output accuracy of each EMG channel, a square wave signal with a frequency of 2 Hz and a peak-to-peak amplitude of 1 mV was applied as the known input signal. Different overall gains (×1, ×50, ×100, ×500, ×1, 000, ×2, 000, ×3, 000, x3, 500, ×5, 000) were then entered into the AMLAB module. The relationship between the input and output square waves and the known and measured amplitudes are displayed in Figure 1.

The amplified and undistorted square waves in the middle traces (x 3, 000 and x10, 000) of Figure 1 indicate that the low and high frequency components of the input signals are preserved and the frequency response of the channel is adequate to faithfully reproduce an amplified and undistorted version of the input. The lower part of Figure 1 shows the gain calibration curve for a typical EMG channel in the system. The calibration test was used as an occasional check to ensure that the EMG channels including the analog module (bioamplifier), the designed EMG processing instrument, the connections and procedures are operating as desired.

To check the validity of the frequency domain representations in each EMG channel, a 1mV sine-wave with frequencies of 10, 40, 50, 60,140 Hz were generated by

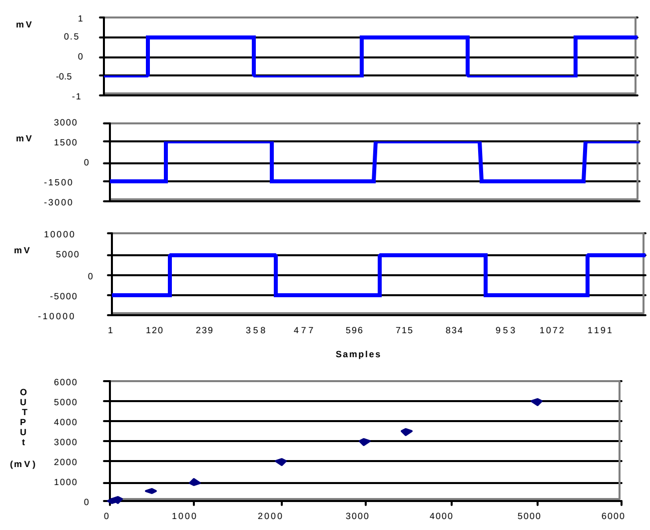

Figure 1. Test input-output waveforms and calibration curve for a typical EMG channel. Only gain settings of x3, 000 and x10, 000 are shown (middle traces).

the signal generator and were applied to the input of each channel. A sampling rate of 1000 Hz was used to sample the sine-waves. A 1024-point Hamming window was used to time limit the sampled sine-waves. Figure 2 shows the magnitude spectra of these signals indicating that the frequency-domain measurements are accurate.

In order to verify the accuracy of the interfaced ROM and torque signals from KIN-COM dynamometer to AMLAB environment, these signals were tested against a satisfactory known standard. The known standard for ROM signals was a digital angle finder (Smarttool® Macklanburg-Duncan, Oklahoma City, OK, USA) with angular accuracy of 0.1 degrees. At first the KIN-COM lever arm was set in the horizontal position and then by changing the offset value, the baseline for angle data was established. Then the KIN-COM lever arm was moved to a vertical position (starting position of the test). In this new position, the gain and offset values of the AMLAB instrument were adjusted to meet the target angle while the instrument was running. Then to check the accuracy of the set-up the KIN-COM lever arm was moved to different positions and the accuracy of readings in AMLAB was checked by comparing them with the values in the angle finder.

The known standard for calibration of the interfaced raw torque signals in AMLAB workstation was a digital hand-held force gauge (Mecmesin Limited, West Sussex, UK) with accuracy of 0.1 Kg. At first the KIN-COM lever arm was set in vertical position and then by changing the offset value, the baseline for torque data was established. Then the hand-held dynamometer was used to vertically apply a known force (i.e. 100 Newton) to the load cell attachment (single pad attachment). The gain and offset values for torque signals were adjusted to meet the target torque value while the instrument was running. Then to check the accuracy of the set-up, the hand-held dynamometer was used to vertically apply a set of different known forces (i.e. 10, 35, 70 and 120 N) to the load cell attachment and the accuracy of displayed values in AMLAB were checked.

To check the accuracy of the designed AMLAB-based instrument for compensation of limb weight, the torque produced by a known weight (15 N) was compared with and without weight compensation in 10-degree increments through 180 degrees of passive excursion of the lever arm starting from the vertical position (see Fig. 3). This procedure was repeated 10 times and the data were recorded and averaged by the AMLAB workstation.

III. EXPERIMENTAL METHODS

A 35-year old asymptomatic female subject and a 37-year old female patient with idiopathic CTS consented to participate in this study. The asymptomatic subject did not report any current neurological or upper quarter musculoskeletal injury. The CTS was diagnosed by a hand surgeon and confirmed by electroneuromyography (ENMG).

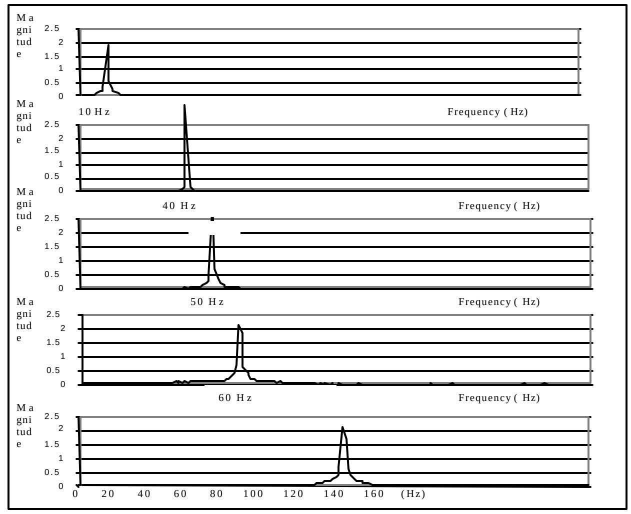

Figure 2. The magnitude spectra of a 1 mV (1024 sample long) sine-wave with frequencies of 10, 40, 50, 60, and 140 Hz applied to the input of a typical EMG channel to validate its frequency-domain accuracy.

Each subject was evaluated while lying in the supine position on a wooden plinth. The arm to be tested was placed in a Range-of-Motion Control Device (ROM-CD) and the position of the elbow forearm and wrist and fingers were fixed and held by ROM-CD locking mechanisms prior to the test. Then the subject's elbow axis, ROM-CD elbow axis and the KIN-COM lever arm axis were aligned. The start and stop angles in the KIN-KOM dynamometer were set at 90 and -30 degrees. Then, the subject was instructed to use a hand-held electronic marking switch at pain onset and pain limit during slow passive elbow extension. The subject was requested to completely relax during the test. After a practice trial, one comparable trial to the point of pain limit was conducted for data collection. The passive elbow extension was held at this point for 3 seconds.

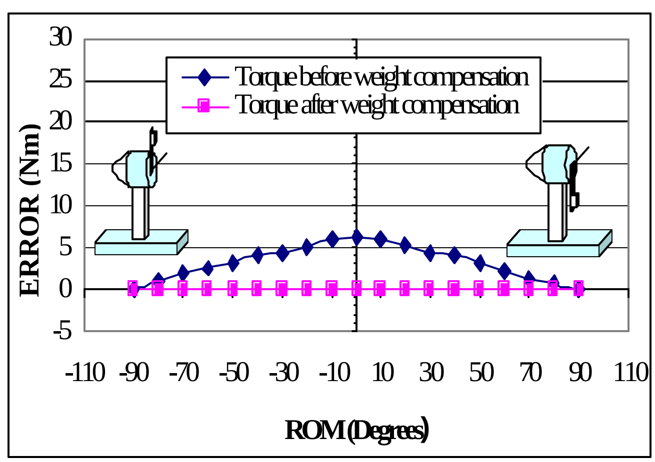

Figure 3. Average error (10 trials) of interfaced raw torque signals from KIN-COM dynamometer with and without weight compensation in the AMLAB environment.

The subject was able to immediately stop the movement using a hand-held button at any point in this range.

The EMG activity was obtained with self-adhesive pre-gelled disposable surface electrodes (DUO-TRODE® MYO-TRONICS, INC. USA). After a standard skin preparation procedure of disinfecting, shaving and abrading, pairs of electrodes were positioned over the site of placement on upper and middle fibres of trapezious, biceps, brachials, pectoralis major and flexor carpi radialis, lower fibres of trapezious, triceps, deltoid, and infraspinatus referenced to anatomical landmarks. A grounding lip-clip electrode was also clipped onto the subject's lower lip.

IV. RESULTS

Following the mechanical stimulus (passive elbow extension), the system successfully acquired, processed and displayed the EMG signals from the involved muscle group, the ROM/Torque signals from the dynamometer and the digital signal from the subject hand-held pain switch. Figure 4 shows the elbow joint ROM signal, the elbow flexor resistive torque signal, the electrical signals for report of pain, and 10 channel of EMG signals acquired from the shoulder girdle and arm muscles in one integrated window.

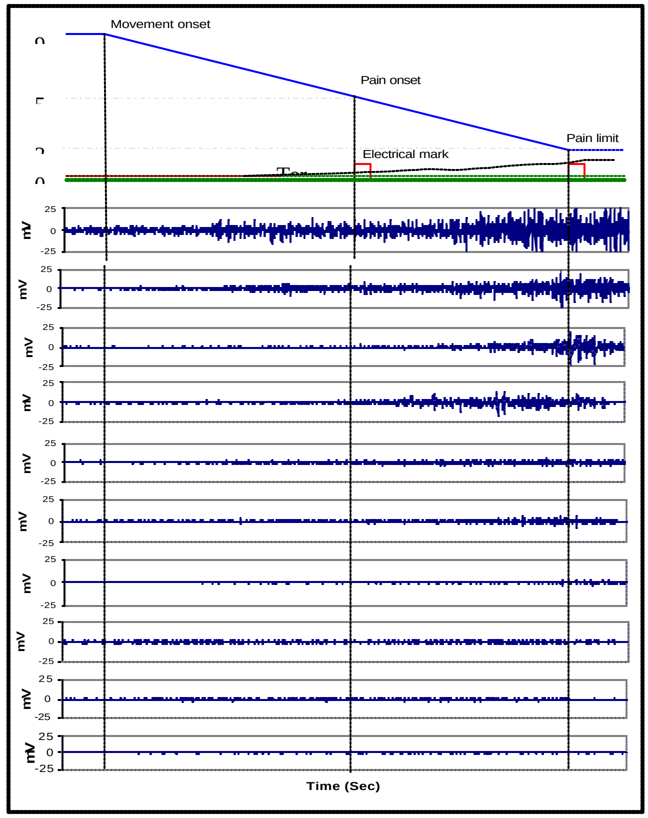

Figure 4. Synchronized and correlated ROM, torque, pain, and EMG signals from 10 shoulder girdle and arm muscles in one integrated environment.

V. DISCUSSION

The developed EMG system provides a hands-free set-up for measuring the response to mechanically evoked stimuli. This capability enables the researchers to control and run a complex experimental set-up (i.e. a dynamometer, a pain switch, an electrical stimulator, multi-channel EMG data collection, and a workstation) single-handedly and saves on researcher's time. This arrangement provides a cost-effective, flexible, and efficient method to design sophisticated experimental procedures and to control the quality of the data during collection and immediately repeat the procedure in case something goes wrong.

The data acquired by the system can easily be edited and exported to various applications such as Excel, Lotus 123, or other spreadsheet packages, as well as into graphics, statistical utilities and other application programs for further analysis. It is also possible to browse through the captured data and extract sections for direct export into third party packages.

The data can be simultaneously recorded and stored as "archive" files. The data can be viewed or stored in epochs called sessions. Sessions can be displayed in real time or could be reviewed later by running the session "off-line".

VI. CONCLUSIONS

In this paper, we described a computer-based integrated signal acquisition and processing system suitable for quantitative study of upper limb movements. This multi-channel system is capable of simultaneous recording, analysis, and display of EMG, range of motion, resistive torque and pain signals.

It provides a cost-effective, flexible, user-friendly and integrated environment to implement sophisticated experimental procedures to acquire and analyze EMG and upper limb movement data. It removes the limitations associated with "single function instruments" and enables the researchers to compare and correlate various signals in one integrated environment.

Even though this system was designed to specifically study the patterns and nature of the evoked motor responses in subjects with Carpal Tunnel Syndrome, it could equally well be modified to allow acquisition, processing, and analysis of EMG and other movement signals in neurophysiology, biomechanics, ergonomics, and kinesiology. This system shows great promise as a modern productivity tool in future research and clinical work.

REFERENCES

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[2] AMLAB® User Manual, 1997.

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